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# Stirling Powered Van Program Overview

Richard K. Shaltens  
National Aeronautics and Space Administration  
Lewis Research Center

Work performed for  
**U.S. DEPARTMENT OF ENERGY**  
**Conservation and Renewable Energy**  
**Office of Vehicle and Engine R&D**

Prepared for  
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Detroit, Michigan, February 24-28, 1986



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Richard K. Shaltens  
National Aeronautics and Space Administration  
Lewis Research Center  
Cleveland, Ohio 44135

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## STIRLING POWERED VAN PROGRAM OVERVIEW

Richard K. Shaltens  
National Aeronautics and Space Administration  
Lewis Research Center  
Cleveland, Ohio 44135

### SUMMARY

The Stirling Powered Van Program (SPVP) is a multiyear, multiphase program to evaluate the automotive Stirling engine (ASE) in Air Force vans under realistic conditions. The objective of the SPVP is to have a manufacturer and end user(s) (i.e., on the path to commercialization) of the second-generation Mod II ASE upon completion of the Automotive Stirling Engine Program in 1987. In order to meet this objective, the SPVP must establish Stirling performance, integrity, reliability, durability, and maintainability. This paper reviews the ASE Program background leading to the Van Program and focuses on plans for evaluating the kinematic Stirling engine in Air Force vans. Also discussed are the NASA technology transfers to industry that have been accomplished and those which are currently being developed.

### ASE PROGRAM BACKGROUND

The Automotive Heat Engine Program was initiated in 1971 by the Environmental Protection Agency (EPA) with a program objective of reduced emissions. EPA added new objectives of improved fuel economy and multifuel capability in 1973. The Automotive Propulsion Research and Development Act of 1978 (PL 95-238) was the enabling legislation for the development, testing, and demonstration of advanced propulsion systems, which included the Stirling cycle. The Department of Energy (DOE) assigned the NASA Lewis Research Center the management responsibility for the Automotive Stirling Engine (ASE) Project through an interagency agreement in 1977. Management of a major engine development contract and responsibility for the supporting research and technology (SR&T) activities are included. Over \$100 million has been expended by DOE on this ASE Program to date. In March 1978, a Stirling engine development contract, funded by DOE and managed by NASA Lewis was awarded to Mechanical Technology Inc. (MTI), Latham, New York. The purpose of the contract was to develop an automotive Stirling engine while concurrently transferring Stirling technology to the United States from United Stirling AB (USAB), Malmo, Sweden. In addition, NASA Lewis conducted extensive in-house and contract research/technology activities to provide support for the engine development effort in certain critical areas. The MTI ASE development contract calls for the design and maintenance of a reference engine system design (RESD) to serve as a focal point for all component, subsystem, system, and engine developments within the project. The RESD is the best "paper" Stirling engine embodying the latest technology reasonably expected to be developed over the life of the project. Mod I engines are first-generation experimental versions of the RESD engine and were built using the best technologies available in the early phases of the project.

Seven experimental automotive Mod I Stirling engines were built and have operated in test cells and vehicles for over 14 000 hr (as of December 1985).

They are now being used to develop and demonstrate new technologies for the second-generation Mod II ASE which will be tested in early 1986. A comparison of the Mod I and Mod II engines is shown in figure 1.

The Mod II engine will be a second-generation experimental version of the latest RESD which is described in reference 1. It is expected to incorporate many of the RESD technologies, and it will benefit substantially from the experience gained from the Mod I engines. A detailed cost analysis and life cycle costs show that cost of ownership of this RESD is comparable to both the spark ignition and diesel engines described in reference 2. The experimental Mod II engine is expected to demonstrate ASE Program goals (presented later) by September 1987.

The Stirling engine system (SES) design of the Mod II (fig. 2) includes the necessary auxiliaries to operate the engine. The design was completed in 1985. The current Mod II design is rated at 63 kW (84.5 hp) at 4000 rpm with a heater head temperature of 820 °C. A major objective of the Mod II design was to reduce the complexity and manufacturing cost of the basic Stirling engine (BSE). The BSE is a Stirling engine without auxiliaries and controls. Previous Stirling engines, such as the Mod I, use two gear-coupled crankshafts and a multipiece engine block. The Mod II, however, uses a single crankshaft and a one-piece, cast-iron V-4 engine block. The Mod II also incorporates an annular heater head, a rolling element drive unit, a metallic preheater, a simplified combustor which features a combustion gas recirculation (CGR) system, a lightweight piston/rod design, and a simplified auxiliaries/control system. The first Mod II ASE will begin dynamometer testing at MTI in early 1986. The designs of the Mod II BSE and SES are described in references 3 to 5.

ASE Program goals are to provide fuel economy which will be at least 30 percent better than that of a comparable spark-ignition (SI) powered vehicle and acceleration at least equal to that of a comparable vehicle in the same weight class. The Mod II is projected to provide a combined mileage of over 42 mpg and to have an acceleration time of less than 13 sec (0 to 60 mph) when installed in a General Motors Celebrity vehicle, which is in the 3125-lb inertia weight class. Mod II fuel economy over the combined urban/highway EPA driving cycle is projected to be 50 percent above the 1984 U.S. fleet average for the 3125-lb inertia weight class. Additional objectives include the following: emission levels that meet or exceed Federal Research Standards (0.41/3.4/0.4/0.2 g/mile, HC/CO/NO<sub>x</sub>/particulates); the ability to use a broad range of liquid fuels; and suitability for low cost mass production. The ASE Program, with the Mod II Stirling engine, is expected to meet or exceed program goals and objectives by September 1987. Characteristics of the Mod II ASE in the baseline vehicle are shown in figure 3.

The Industry Test and Evaluation Program (ITEP), which provided Mod I engines for test and evaluation by industry, was successfully completed in 1984. Results of the ITEP from both industry participants, General Motors Research Laboratories (GMRL) of Warren, Michigan, and Deere & Company of Moline, Illinois, were favorable. The experimental Mod I engines were operated by GMRL and Deere with no major hardware failures. Both GMRL and Deere prepared final public reports (refs. 6 and 7) on their evaluation of the experimental Stirling engine systems.

During 1985, ASE Program briefings, which reviewed the progress of Stirling technology and the ASE Project, were given to industry and other government agencies. As a result, NASA Lewis became aware of a number of nonautomotive applications for the kinematic Stirling engine. These include both commercial and military applications such as irrigation pumps, delivery vans, generator/compressor sets, heat pumps, and submarine power sources. Attractive features for the applications include better fuel efficiency, potential for increased reliability, lower maintenance costs, reduced noise levels (no muffler required), lower vibration levels, lower infrared signature, reduced undesirable emissions (no catalytic convertor required), plus the potential for multifuel capability. In addition, particulate traps are not required when using diesel fuel.

Although Stirling appears to have many advantages to the military, they are not likely to make a significant commitment to employ the ASE until a commercial base has been established for the supply of engines, including the necessary spare parts. At this time, only limited operational data are available from the ASE Program. These data provide little or no assurance to potential manufacturers and users that the risk has been sufficiently reduced for the industry to complete the development of the Stirling engines as well as associated controls.

Briefings to automobile industry management of the ASE Program and status have included General Motors Research Laboratory (GMRL), Ford, Chrysler, and American Motors Corporation (AMC). Comments from GMRL and Ford management personnel tend to summarize the view of the American automobile industry as follows:

GMRL. - It does not appear likely that the advanced powerplants currently under development will replace the internal combustion engine in the automotive passenger car. GMRL personnel also believe that Stirling needs a starter market in other applications where limited production and in-use experience could be gained. However, GMRL feels that Stirling engines are potentially attractive for other applications such as heavy-duty trucks.

Ford. - Although the Stirling engines, in general, have very desirable features, they do not believe that the Stirling is ready for use in the automotive passenger car. Ford did state that they see specific applications in nonautomobile use, possibly for light trucks, where the Stirling engine may be the powerplant of choice.

A follow-on to ITP is the Government and Industry Participation Program (GIPP), which is to provide additional testing (focused on longer operation) and evaluation of Stirling engines by U.S. industry and other government (Federal, State, county, and local) agencies. GIPP was advertised in the Commerce Business Daily on May 16, 1985. The program under GIPP offers the loan of used Mod I engines to industry in order to expand the current Stirling technology base. The intent is to familiarize potential manufacturers and/or users with the current technology, and to evaluate the engines for other nonautomotive applications.

NASA Lewis has put together an industry and government team, through GIPP, to evaluate the government-owned Stirling engine in Air Force (AF) delivery vans and to assess the Stirling technology in real world environments. No ASE Program resources were available for GIPP. However, the NASA Technology

Utilization (TU) Division is providing the funding for the Stirling Powered Van Program to create an opportunity for industry to develop marketable products and transfer NASA's technology.

### STIRLING POWERED VAN PROGRAM (SPVP)

The objective of SPVP is to have a manufacturer and end user(s) (i.e., on the path to commercialization) of the second-generation Mod II Automotive Stirling Engine (ASE) at the completion of the ASE Program in September 1987. A multiyear, multiphase program is planned to involve a potential manufacturer and end user(s) in evaluating a first-generation Mod I ASE in Air Force vans under realistic conditions. Prime objectives of the three-phase SPVP are as follows: (1) to obtain early operation and performance data while gaining initial experience in the operation of Stirling engines in a typical user environment; (2) to evaluate the Stirling engine under realistic conditions to help establish Stirling integrity, reliability, and durability; and (3) to accelerate the development of Stirling engines and enable the earliest possible use of the second-generation Mod II ASE. Phase I would provide for the installation and operation of a Mod I ASE at 720 °C in an Air Force delivery van operated in a moderate climate. Phase II would evaluate the Mod I ASE at 820 °C installed in a van operated in different climates and user conditions. Mod II ASE technologies would be incorporated during Phases I and II on the Mod I systems as they become available and ready for field testing. Phase III will evaluate the Mod II ASE at 820 °C installed in van(s) based on the results of phases I and II. Phase I is scheduled to begin with a kickoff meeting of all participants for finalization of agreements and responsibility for assignments in early 1986.

Phase I. - In early 1986 a used Mod I Stirling engine from the ASE Project will be refurbished by MTI. The engine is rated at 53 kW (71 hp) at an operating temperature of 720 °C. It will be operated primarily on unleaded gasoline. The engine will first be characterized in a dynamometer test facility to determine engine performance. After performance mapping is complete, the Stirling engine, auxiliaries, and control system will be installed in an appropriate Air Force delivery van. The delivery van, designated a "multistop" by the Air Force, is a vehicle designed to transport personnel and light cargo in a stop-and-go duty cycle. A typical Air Force multistop is shown in figure 4. After checkout to assure satisfactory operation, the van will be delivered to Langley AFB, Virginia, for evaluation by the Management and Equipment Evaluation Program (MEEP) personnel under Air Force Tactical Command (TAC). The goal of Phase I is to operate the MOD I ASE at least 1000 hr in actual mission use in moderate climates prevalent to Langley. Operations will include stop-and-go driving, long-distance/high-speed driving, and considerable operation at idling conditions. It has been estimated that nearly 70 percent of the operating time will be at idle conditions, typical of Air Force multistop operations. Evaluation of the operating experience with the Stirling engine installed in the Air Force van will be made after 100 and 500 hr to determine if sufficient progress has been made to continue with the SPVP.

The initial 500 hr of operation will be a learning phase for Air Force personnel. Emphasis will be on familiarization and training in the operation of the Stirling powered Air Force van. Upon successful completion of the first 500 hr using unleaded fuel, the Stirling powered van then will be operated on

both unleaded gasoline and JP-4 aircraft fuel to demonstrate multifuel capability. These fuels will be alternated in a "blind" test with driver/tester evaluations being conducted without knowledge of which fuel is being used. After the initial 500 hr of operation, a decision will be made whether to proceed into Phase II of the SPVP. Upon completion of the 1000 hr of operation, additional multifuel testing is planned. Fuels under consideration include diesel, JP-8, Jet A/A1, and methanol. Throughout the Phase I tests MEEP personnel will regularly evaluate the Stirling engine fuel usage, performance, emissions, and condition of the lubricating oil in the engine crankcase. Analysis of component reliability, maintenance procedures, and schedules will be made to determine the potential for achieving the lower life cycle costs claimed for the Stirling. Maintenance and repair history will be analyzed and recommendations formulated. Recharacterization of the Stirling will take place at the completion of Phase I to determine if any engine performance degradation has taken place. The engine will then be completely torn down for a detailed inspection and analysis to determine any internal component deterioration. A report will be prepared documenting the Phase I experience at Langley.

Phase II. - It is expected by early 1987 that a second used Mod I Stirling engine from the ASE Project will be refurbished by MTI. Developed Mod II technologies such as CGR and/or improved auxiliaries may be added to the Mod I Stirling engine system (SES) as they become available and are ready for field testing. This engine will be rated at 60 kW (80 hp) at an operating temperature of 820 °C (an increase of 100 °C from Phase I) and will be operated on unleaded gasoline. The engine will undergo the usual performance testing in a dynamometer facility as in Phase I. Installation of the engine will be performed by Air Force personnel in the appropriate Air Force van at Langley. After checkout to verify proper operation, the Stirling powered van will be operated about 100 hr at Langley to train and familiarize new MEEP personnel from Air Force System Command with the operation and maintenance of this Stirling powered Air Force van. Performance comparisons will be made with the Phase I van installation as appropriate. Also, load carrying and/or towing evaluations will be made.

The goal of Phase II is to accumulate at least 1000 hr of operation under actual mission use in various climates and user conditions. Phase II is expected to accumulate at least 250 hr of operation at each of three additional MEEP facilities. One facility is located within Air Force System Command (AFSC) at Eglin AFB, Florida (hot/humid), one in Air Training Command (ATC) at Randolph AFB, Texas (hot/dry), and another within Space Command (SPACECOM) at Peterson AFB, Colorado (cold/dry/high altitude). Upon successful completion of testing at these facilities, operation in real world environment of a commercial fleet operator is planned for at least 250 hr. After an accumulation of at least 1000 hr of operation during Phase II, recharacterization and a complete teardown of the Mod I engine is planned. Throughout Phase II a detailed account of the operation, maintenance, and repair of the Stirling engine system as installed in the Air Force van will be documented. As in Phase I, MEEP personnel will regularly evaluate engine fuel consumption, performance, emissions, and oil quality. A report will be prepared documenting the Phase II evaluations.

Phase III. - Currently, Phase III planning is to be initiated by industry in late 1987. The MEEP facility within the Strategic Air Command (SAC) at Offutt AFB, Nebraska, has been identified for evaluation of a second-generation



Mod II ASE in an Air Force van. This part of the Test Program will be developed based on the results of Phases I and II.

#### PROJECT TEAM

The Stirling Powered Van Program is to be cofunded by joint Space Act or interagency agreements with NASA (Lewis). The project team includes NASA Lewis, the Department of Energy, the Department of the Air Force, Deere & Company, Purolator Courier, and the American Trucking Associations. Mechanical Technology Inc. (MTI) is the prime contractor for the automotive Stirling engine development.

The Stirling Engine Project Office at NASA Lewis will provide overall management responsibility for the Van Program and technical expertise on Stirling. Resources have been provided by the NASA Technology Utilization Division for Phases I and II of the SPVP, while technical direction will be provided through an existing Lewis Contract (DEN 3-32) with MTI. Significant industry support will be required for Phase III of the Van Program to meet the program objectives. Coordination of all program functions is the responsibility of NASA Lewis.

The Department of Energy (DOE), Conservation and Renewable Energy, Office of Vehicle and Engine R&D, is providing the loan of the Mod I and Mod II Stirling engine(s) from the ASE Program, at no charge, for the Van Program under GIPP.

The Department of the Air Force, Vehicle System Program Managers (VSPM) evaluate a wide range of commercial equipment under their Management and Equipment Evaluation Program (MEEP). MEEP facilities are located throughout the United States and can provide a variety of user conditions and environments to enable the user to assess the potential of newly developed powerplants such as the kinematic Stirling engine. The Air Force is providing their expertise and facilities for the evaluation of a NASA-supplied Stirling engine(s) in Air Force supplied van(s). MEEP managers believe that the Stirling engine has the potential to provide a reliable, multifuel, low-maintenance powerplant for Air Force use.

#### INDUSTRY PARTICIPANTS

Industry participants include Deere & Company of Moline, Illinois, Purolator Courier of Basking Ridge, New Jersey, the American Trucking Associations (ATA) of Alexandria, Virginia, and Mechanical Technology Inc. of Latham, New York.

Deere & Company is a leading manufacturer of equipment used in construction, agriculture, forestry, landscaping, materials handling, and other applications. Deere is sharing their manufacturing expertise and the use of their facilities to help provide the necessary testing and evaluation of the kinematic Stirling engine in the Van Program. Deere believes that a number of potential applications and markets may exist for the Stirling engine. Their interest, if the engine's potential is verified, is to be able to manufacture, on a profitable basis, Mod II type Stirling engines.

Purolator Courier, a fleet operator of over 5000 vehicles, is engaged in the delivery of express mail and small packages in the United States. Purolator has been involved as an evaluator of engines and associated hardware for the automotive industry for over 20 years. Evaluations have been made on advanced and prototype hardware, including preproduction engines under realistic user environments. Purolator's experience as a fleet evaluator for the automotive industry makes the Company a very valuable contributor to the Van Program.

The American Trucking Associations (ATA), Alexandria, Virginia, represents 51 state associations, one for each state and the District of Columbia. The ATA's mission is to serve the united interests of the trucking industry. ATA is interested in making an evaluation of the life cycle costs (LCC) for the Stirling and compare them with current power plants used in the trucking industry.

MTI, the prime contractor for developing the automotive Stirling engine, currently has an existing contract (DEN 3-32) with Lewis, funded by DOE. Under this contract, using NASA TU funding, MTI will provide the necessary services for the refurbishment and modification of Government-owned Stirling engine(s) for the Van Program. MTI will also provide the necessary training, inspection, maintenance, and spare parts for the Stirling engine.

#### NASA TECHNOLOGY TRANSFER FROM THE ASE PROGRAM

As a result of the ASE Program, existing European Stirling technology has been effectively transferred to the United States. This includes the understanding of the basic Stirling cycle. Subsequently, the continued development and operation of the complete Stirling engine system (SES) which includes the engine plus all the necessary auxiliaries required to operate the basic Stirling engine (BSE) has been developed primarily in the United States. Component development tasks included the advancement of Stirling engine technology in terms of reliability/durability, performance, cost, and manufacturing with the primary work focused on areas of combustion, heat exchangers, materials, seals, piston rings, engine drivetrain, controls, and auxiliaries.

At the start of the program all analytical codes were held as proprietary by N.V. Phillips and their licensees. A key objective was to make similar codes available to the public. NASA Lewis developed an analytical code for the kinematic Stirling engine, which has been documented (ref. 8) and the software transferred to the Computer Software Management and Information Center (COSMIC) at the University of Georgia. NASA Lewis personnel are currently developing an analytical code for the free-piston Stirling engine which also is to be transferred to COSMIC.

Low-cost, iron-base materials (alloys CG-27 and XF818) have been identified for the Stirling heater head by NASA Lewis personnel. These materials are capable of withstanding the rigorous requirements of the ASE. Because of the mass production requirements for the automobile application, these alloys had to be low cost and contain a minimum amount of or no strategic materials such as cobalt and chromium. Further requirements imposed on these heater head alloys included good high-temperature strength, oxidation-corrosion resistance, compatibility with hydrogen, and resistance to hydrogen permeation. These alloys must also exhibit good fabricability, weldability, and long-term cycle

operation. Alloys CG-27 and XF818 are currently being used in the first-generation Mod I engines and are discussed in references 9 and 10. NASA Lewis materials engineers are currently evaluating more advanced materials, such as the iron-based alloy 4G-Al (ref. 11) and intermetallics (B2 aluminides) (ref. 12), which may have additional advantages over the selected alloys.

Solid lubricant coatings (PS200), developed by NASA Lewis personnel, exhibit promising friction coefficients ( $0.20 \pm 0.05$ ) and low wear properties up to 900 °C. The PS200 coating (described in ref. 13) appears to have the necessary properties to be used as a lubricant for a hot piston ring in a Stirling engine. This would allow for the piston rings to be physically relocated from a cold region (currently at the bottom of the piston) to a hot region at the top of the piston without ring degradation. Analysis has shown that the potential exists for a significant improvement in the engine power and efficiency (10 to 20 percent) by moving the piston rings from the cold to the hot region in the Stirling engine. This replacement reduces appendix gap losses. NASA Lewis engineers and tribology personnel are currently preparing to evaluate the proposed coating at about 800 °C in a Mod I Stirling engine. If successful, the operation of the hot piston ring in Stirling engines could also prove to be a valuable tool in developing piston rings for advanced spark ignition (SI) and adiabatic diesel engines (ADE) which also require "hot" piston rings. Evaluation of such rings for the SI and ADE are hampered by the presence of contaminants from combustion products and oil residues. The working cycle of the Stirling engine is free from contaminants and the hot piston ring operates in a very clean environment (i.e., pure gas such as hydrogen at nearly 800 °C).

Under development at Coors of Golden, Colorado, is a ceramic preheater (mixed oxide) which has demonstrated good performance and the potential for long life in rig tests at MTI. When developed, ceramic preheaters appear capable of being manufactured at significantly reduced cost and still equal performance of current stainless steel preheater design.

Filament-wound reinforced aluminum pressure vessels (fiberglass bottles) are currently a component of the Mod II ASE SES for use as the hydrogen storage bottle. Features include light weight, improved safety, long life, and lower cost factors. The fiberglass bottle technology was originally developed for NASA.

With the ASE kinematic engine technology as a base, NASA has expanded its Stirling engine activities into free-piston Stirling engines which show considerable promise for space power application. An experimental free-piston Stirling engine has been operated by NASA Lewis engineers and scientists as a research tool to advance Stirling cycle technology. This has permitted a better understanding of the engine dynamics and thermodynamics, the interaction of the load and engine dynamics, and the verification of the analytical codes being developed by NASA Lewis. As a result of this work at NASA Lewis (ref. 14), the free-piston Stirling engine is now considered a good candidate as a dynamic power source for space power applications, either solar or nuclear powered.

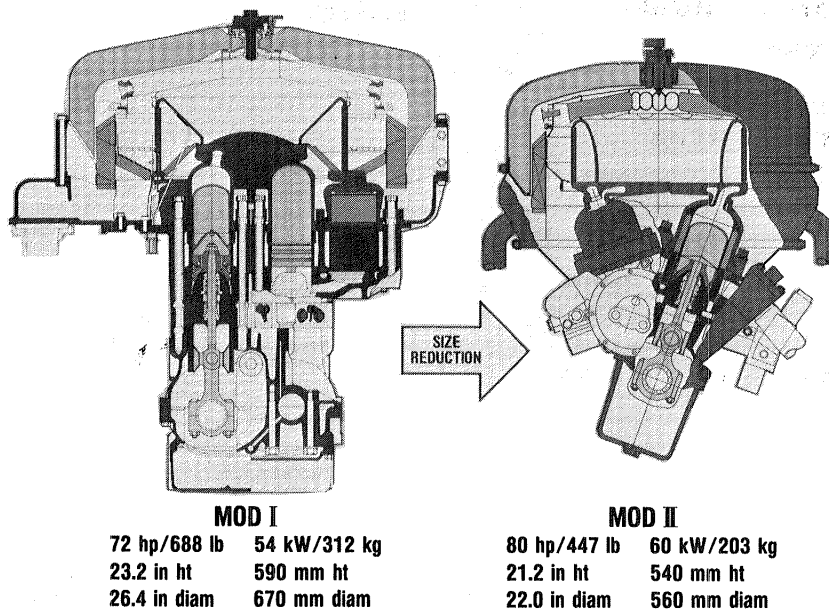
## CONCLUDING REMARKS

The data generated by the Van Program will be obtained over extended operating periods in a variety of real life duty cycles and environments. Specific results should include component and system reliability data along with real world operation and maintenance costs plus life cycle costs. Evaluations conducted under realistic conditions should be of considerable help in establishing Stirling operational integrity. The Van Program is necessary to ensure that the proper testing by potential users is completed, thereby providing to industry valid data to make technical decisions relative to the Stirling as an alternative power plant. Data from the program will also provide information which should aid in reducing some of the manufacturing risks for potential U.S. manufacturers and enhance the probability for commercialization by U.S. industry.

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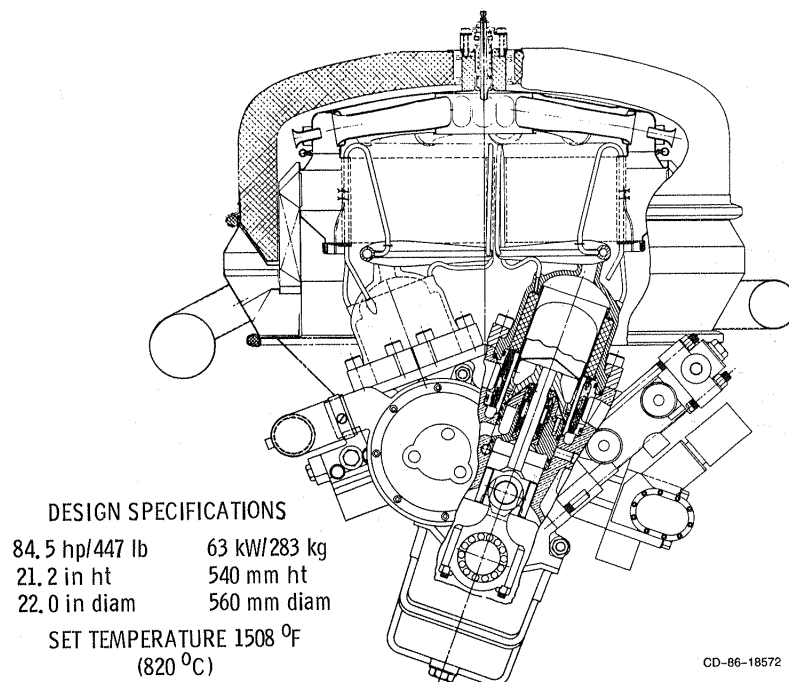
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Figure 1. - Comparison of Mod I and Mod II engines.



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Figure 2. - Mod II engine design.

**BASELINE PERFORMANCE**  
**MOD II IN A '85 CELEBRITY**

**FUEL ECONOMY**

CITY	33.0 mpg
HIGHWAY	63.2 mpg
COMBINED	42.0 mpg

**ACCELERATION**

0 TO 60 mph	13.0 sec
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**EMISSIONS**

NO <sub>x</sub>	LESS THAN 0.4 g/mi
HC	LESS THAN 0.41 g/mi
CO	LESS THAN 3.4 g/mi
PARTICULATES	LESS THAN 0.2 g/mi

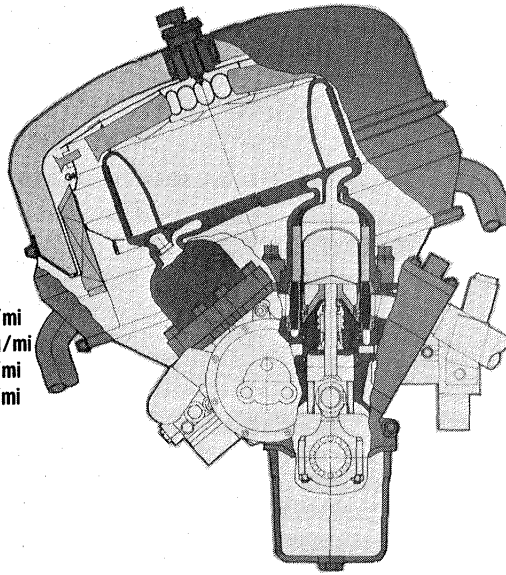


Figure 3. - Mod II characteristics in the baseline vehicle.

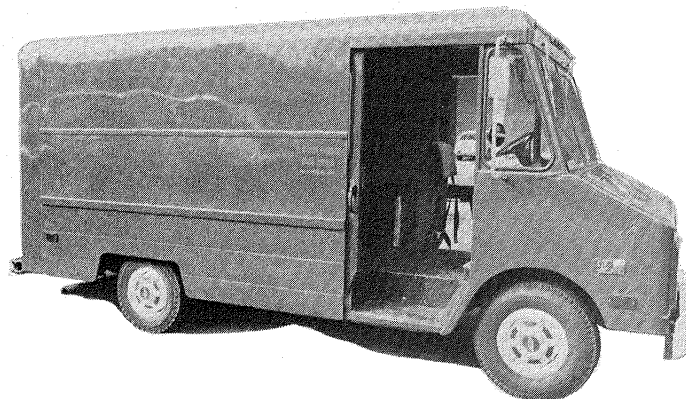


Figure 4. - Typical Air Force multistop van.

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16. Abstract <b>The Stirling Powered Van Program (SPVP) is a multiyear, multiphase program to evaluate the automotive Stirling engine (ASE) in Air Force vans under realistic conditions. The objective of the SPVP is to have a manufacturer and end user(s) (i.e., on the path to commercialization) of the second-generation Mod II ASE upon completion of the Automotive Stirling Engine Program in 1987. In order to meet this objective, the SPVP must establish Stirling performance, integrity, reliability, durability, and maintainability. This paper reviews the ASE Program background leading to the Van Program and focuses on plans for evaluating the kinematic Stirling engine in Air Force vans. Also discussed are the NASA technology transfers to industry that have been accomplished and those which are currently being developed.</b>					
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